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MICROSTIMULATION OF LUMBOSACRAL SPINAL CORD-MAPPING

Contract #N01-NS-8-2301

9th Progress Report
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Neural Prosthesis Program

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I. Introduction

During this quarter studies examining the complex motion of the cats hindlimb to spinal cord microstimulation continued. In addition to examining sites in the L_6 and caudal L_5 lumbar spinal cord we extended our studies to include the L_7 segment. The hindlimb responses seen in L_7, like those in L_6, often involved several muscle groups producing a complex movement which involved several joints as well. The responses elicited in L_7 differed somewhat from that seen in L_6 and caudal L_5. At the dorsal site (0.4 to 2.2mm from spinal cord surface) hindlimb lifting was often elicited by stimulation with a single ipsilateral microelectrode. The hindlimb lifting was similar to that seen in L_6. The hindlimb extension elicited at deeper sites (2.4 to 4.0mm from surface) was directed strongly rearwardl rather than a single downward extension as seen in L_6. The extension seen in L_7 gave the appearance of an extension that would lift and move the animal forward. See details of these studies below.

During this quarter pseudorabies virus tracing studies of the colon and anal sphincter also continued.

Preparations are also being made to begin rabies virus tracing studies on the hindlimb skeletal muscle of the cat. These studies seemed necessary since pseudorabies virus was only minimally successful in labeling motoneurons and interneuron innervating skeletal muscle.

II. Complex Hindlimb Movements Generated by Microstimulation of the L_7 Segment of the Lumbar Spinal Cord.

Studies reported on in previous progress reports have described experiments in which microstimulation of a single site in the L_6 and caudal L_5 segments of the lumbar cord produced complex motor activity that involved several joints and several muscle groups. These initial studies demonstrated that focal microstimulation of a single spinal cord site could elicit some rather complex motions often consisting of what appeared to be "functional" hindlimb lifting and extension. In some instances hindlimb abduction and adduction also occurred with lifting and extension. During this quarter we extended our previous mapping studies to include experiments directed at the L_7 segment of the lumbar spinal cord.

A. Methods

The methods used in these studies have been described in detail in progress report #8 and are briefly outlined here.

Adult male cats are anesthetized with pentobarbital (30-35mg/kg I.V.) and rigidly suspended in a spinal cord frame with the hindlimb allowed to move freely. Reflective markers at each hindlimb joint (hip, knee, and ankle) are video taped using two video cameras – one from the left side (for left hindlimb) and another from the back of the hindlimb. The motion of the hindlimb generated by spinal cord microstimulation is recorded on video tape and analyzed after completion of the experiment using a computer equipped with a video frame grabber and a CAD (computer aided design) program to measure hindlimb movement on each video frame. Stick figures are generated for each stimulus site from the captured video frames.

Spinal cord sites are stimulated every 200 microns along each electrode track and are identified histologically following completion of each experiment. The histological data is then correlated with the motor output generated at each site.

The stimulus parameters for mapping studies were 0.2 msec duration charge balanced pulses, 40 Hz at 0-100 μA intensity. Pulse intensity was modulated by a sine wave function (see progress report #8).

B. Results

Microstimulation of the left side of the L_7 spinal cord elicited responses primarily in the left hindlimb. The response consisted of a smooth excursion of the hindlimb (either flexion or extension) and a return to it's resting position following termination of the stimulus. The stimulus did not trigger a long lasting rhythmic movement of either hindlimb. The contralateral (the right hind limb in most of our experiments) hindlimb responses were in general minimal and were only seen with microstimulation near the midline. When a response was seen on the contralateral side, it consisted of a small muscle twitch rather then a smooth lifting or extension of the limb.

Figure 2-6 illustrate some typical responses seen along five tracks in the L_7 segment of the lumbar spinal cord. Figure 1 indicates the mediolateral and rostrocaudal position for each track illustrated in Figures 2-6. Track #1 is located about mid L_7 just medial to the dorsal root entry zone (DREZ). The responses along track # 1 are illustrated by the stick figure in Figure 2. The stick figure represents the peak response at each depth from the spinal cord surface. At sites in the dorsal horn and dorsal parts of the ventral horn (from 0.4 to 2.0 mm) focal microstimulation elicited hindlimb lifting with movement about the hip, knee and ankle joints. Little adduction or abduction (bottom Figure 2) of the hindlimb is elicited by stimulation at these dorsal sites. This patten is similar to that seen with stimulation of the L_6 segment of the lumbar spinal cord. At sites in the ventral horn (2.8-4 mm from cord surface) hindlimb extension is elicited . The extension at the L_7 level lifts and projects the hindlimb rearward, rotating the hip joint and extending the knee and ankle joints. This differs from the responses observed in the L_6 ventral horn where a simple downward extension was evoked. In L_7 abduction of the hindlimb was also observed (bottom Figure 2-6) with little adduction. This is somewhat different from L_6 where either abduction or adduction accompanied hindlimb extension.

Track #3 is 600 μm medial to tract #1 (see Figure 1) and the responses seen along this track are shown in Figure 3. Both the hindlimb lifting and rearward extension are weaker at this more medial site. However, the responses along track #5 which is 600 μm lateral to track #1, evokes strong rearward extension with almost no lifting (Figure 4). The strong rearward extension seen at mid L_7 is also seen at more rostral (Figure 6) and more caudal (Figure 5) sites. The abduction of the hindlimb is also maintained over 3-4 mm in the rostral-caudal direction in L_7.

During the next quarter the mapping of L_7 will continue and mapping of the S_1 segment of the sacral spinal cord will commence.

Figure 1. Transverse sections of the L_7 spinal cord showing the position of 15 electrode tracks at three levels (rostral, middle and caudal) of the L_7 lumbar cord. Responses from Tracks 1,3,5,8 and 13 are shown in Figures 2 to 6. Sites are stimulated along each track at 200u intervals. The distance between each transverse section shown is 1mm.

Figure2. Stick figures of the left hindlimb showing the responses elicited at each depth along a given electrode track. Track #1 is shown in this figure (See figure 1 for location of track in middle L_7). The top drawing shows the changes in hindlimb position viewed from the side while the bottom drawing shows the hindlimb position from the back (abduction is movement to the left). The depth in mm is shown along the top of each figure. The maximum response is shown for each stimulus site. Stimulus parameters are: 0.2 msec. duration, 40 Hz, 0-100 uA stimulus intensity modulated by a sinewave function.

Figure 3. Same as Figure 2 except showing data for Track #3.
Figure 4. Same as Figure 2 except showing data for Track #5.
Figure 5. Same as Figure 2 except showing data for Track #8.
Figure 6 Same as Figure 2 except showing data for Track #13.

L7 Spinal Cord

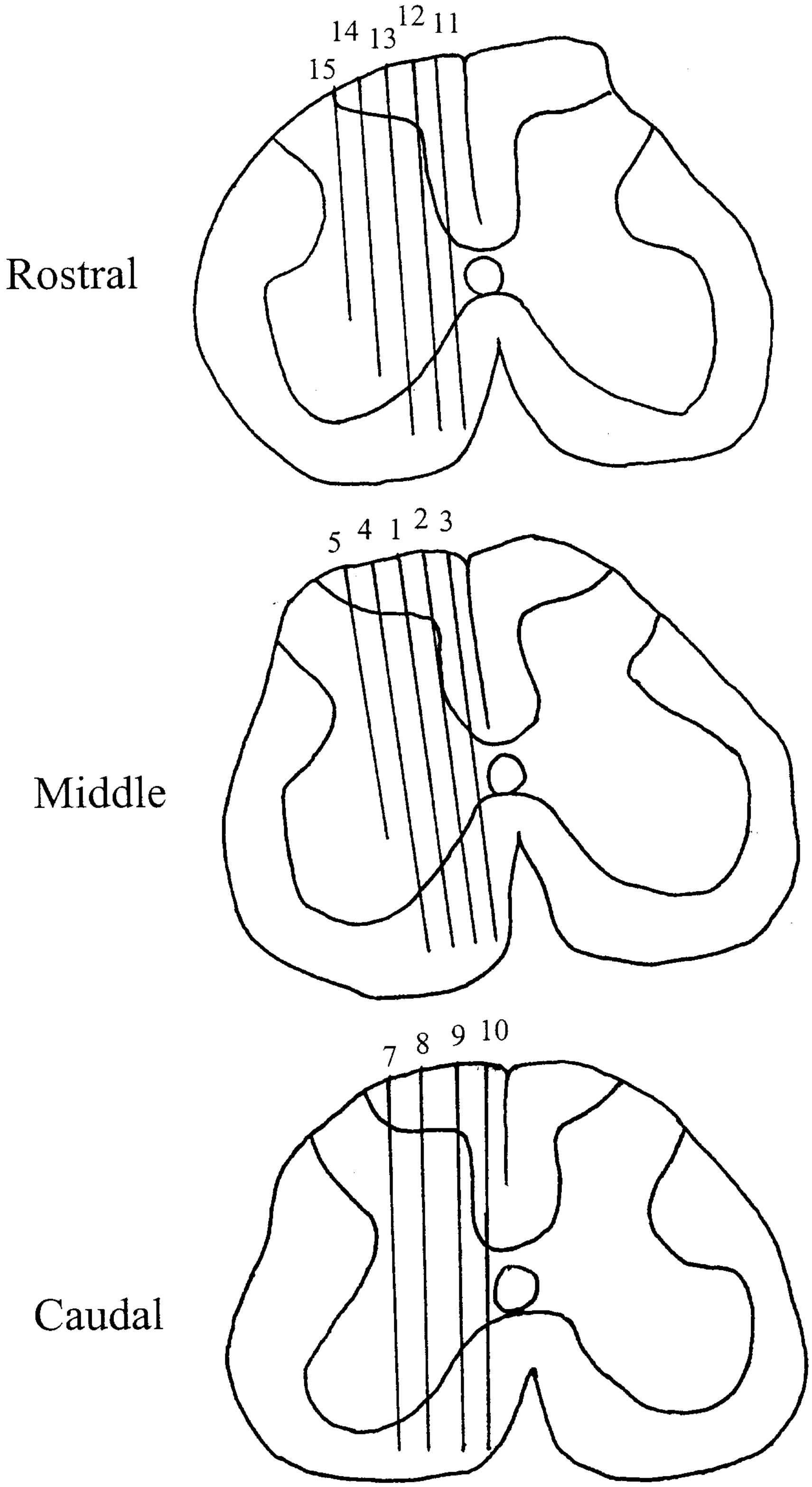
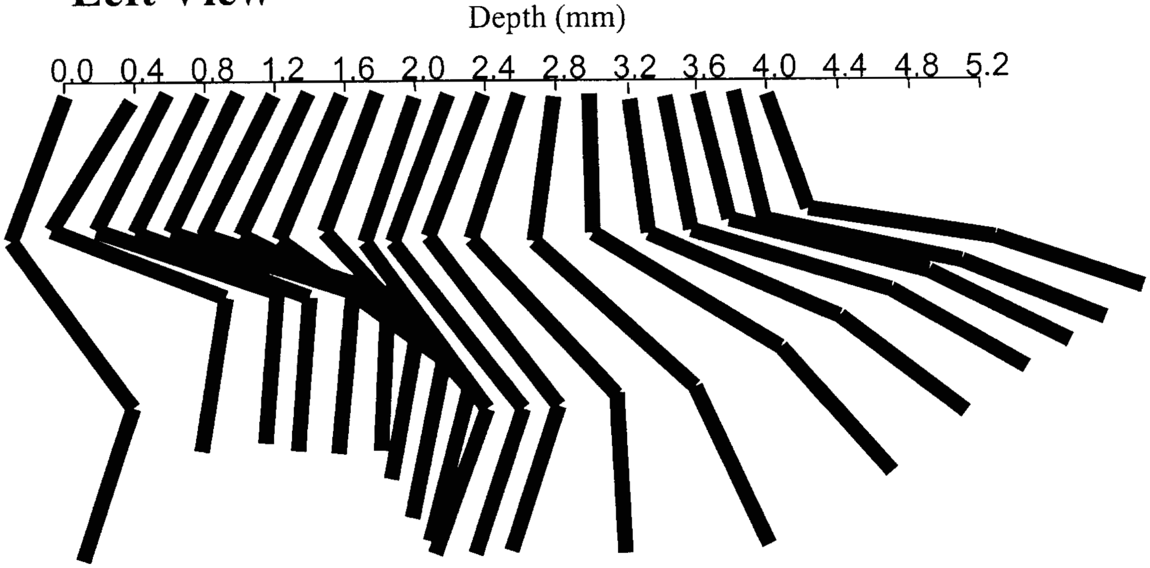


Figure 1

MS#82, Track#1, depth 0.4mm to 4.0mm, No.1-19

Left View



Back View

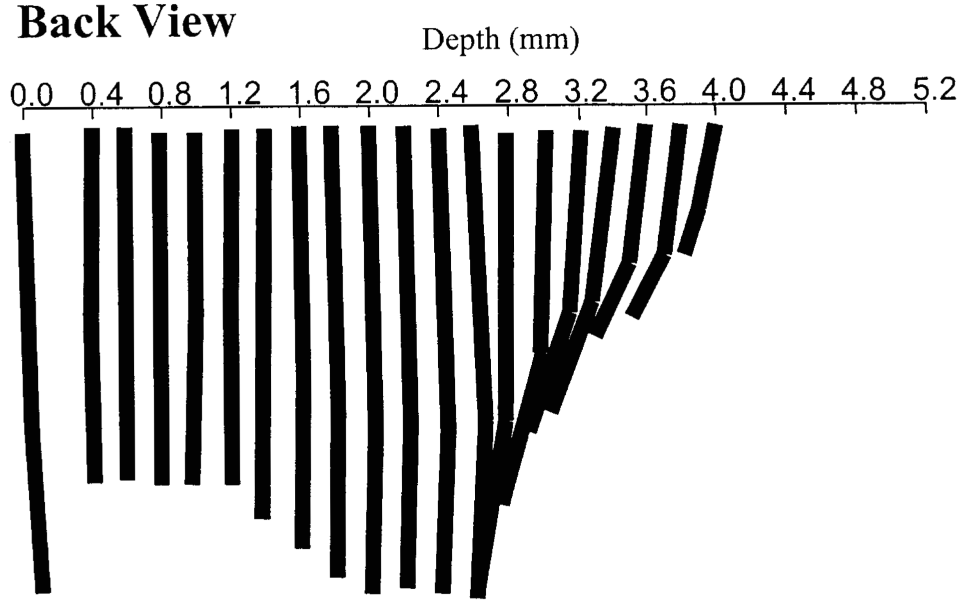
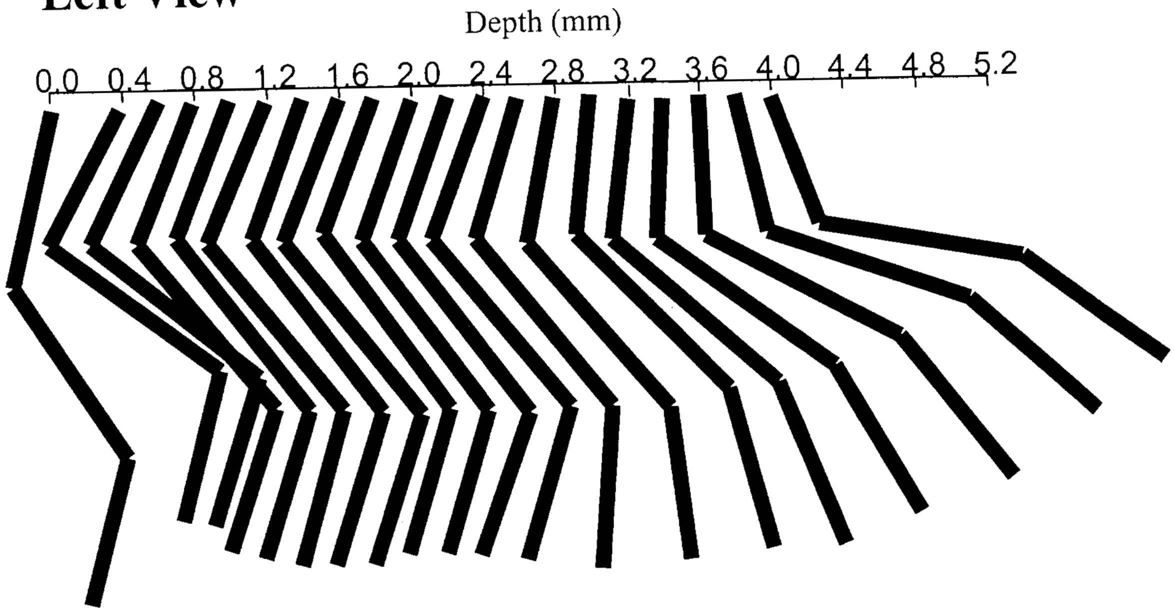


Figure 2

MS#82, Track#3, depth 0.4mm to 4.0mm, No.39-57

Left View



Back View

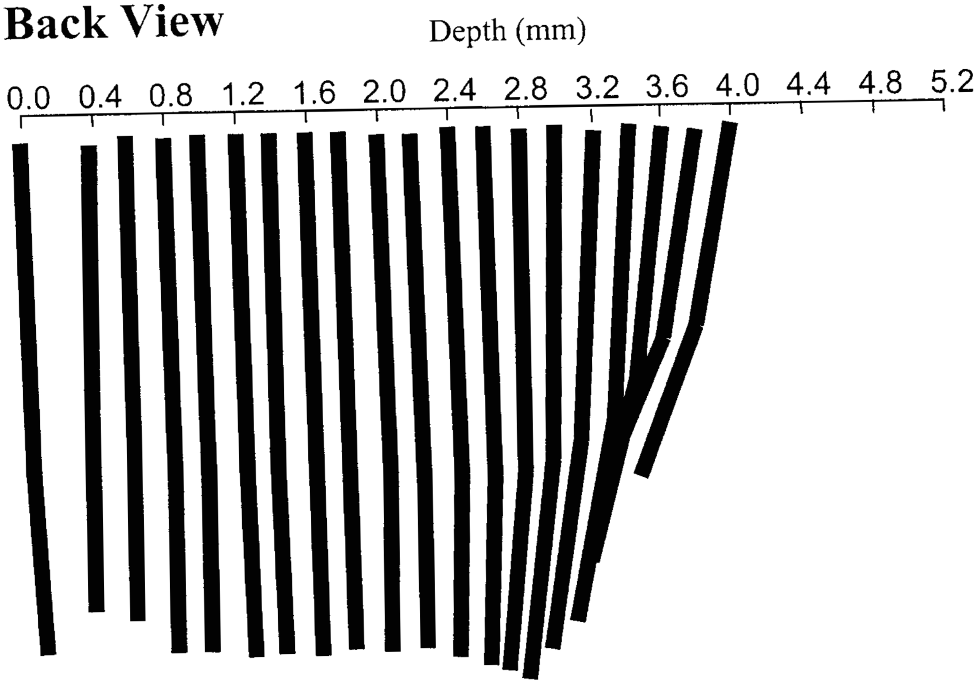
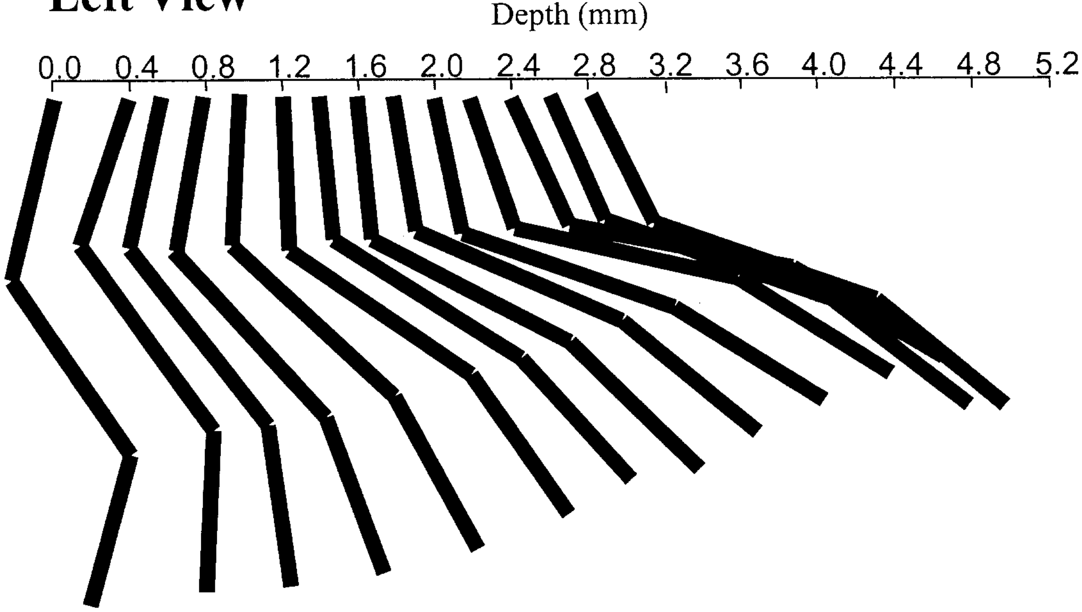


Figure 3

MS#82, Track#5, depth 0.4mm to 2.8mm, No.77-89

Left View



Back View

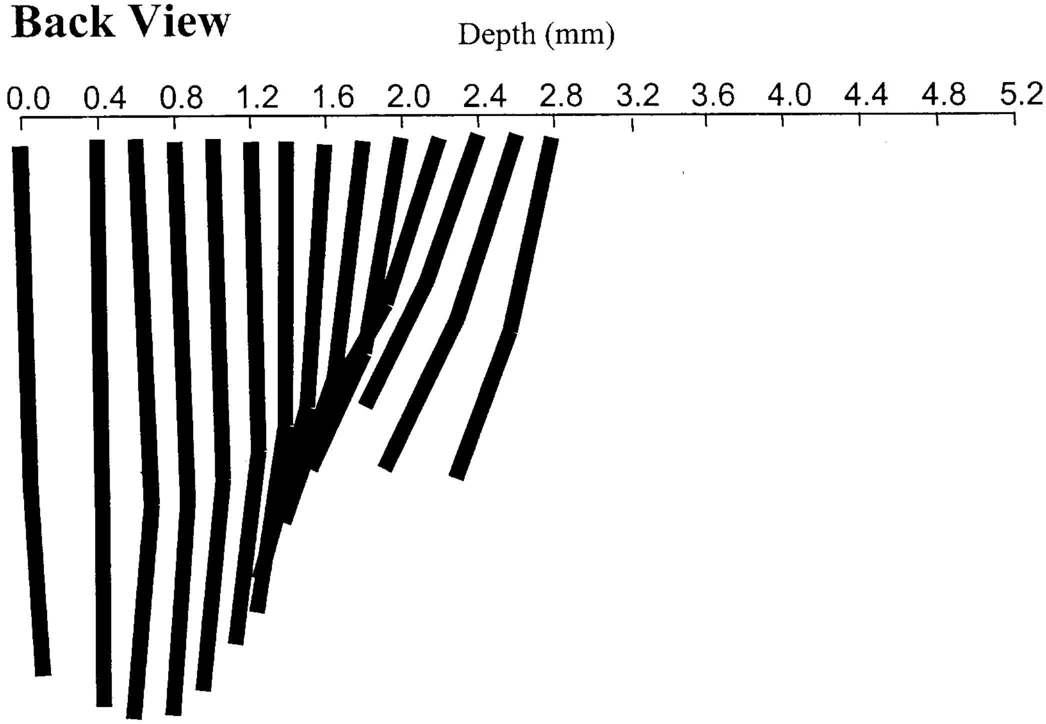
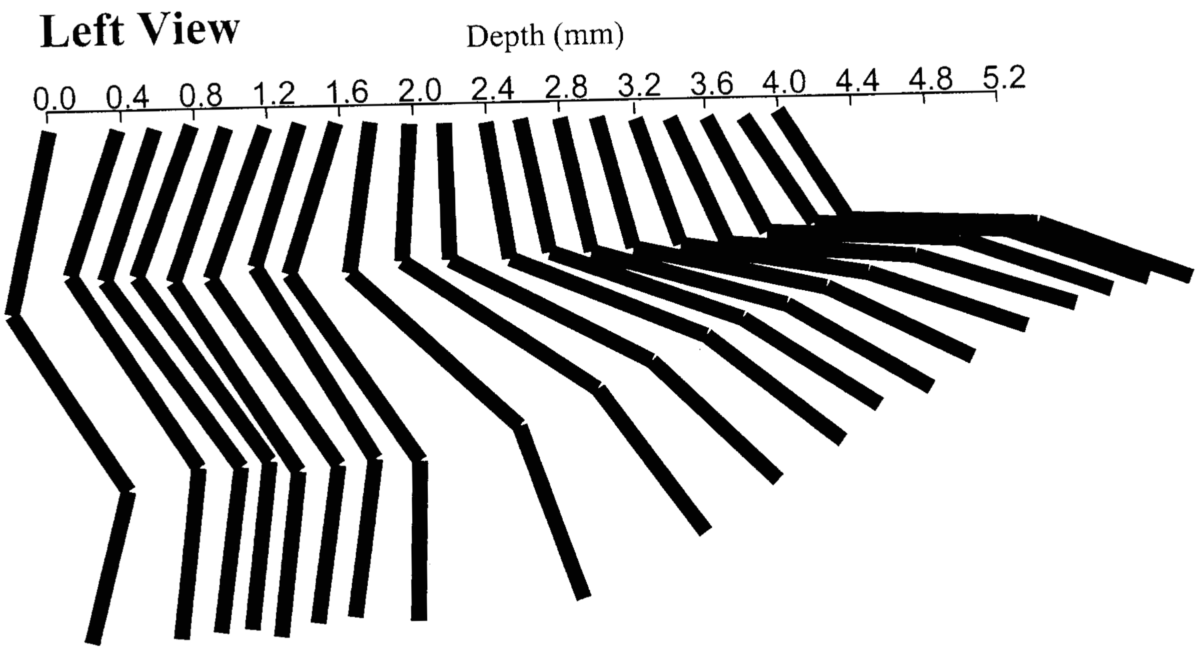


Figure 4

MS#82, Track#8, depth 0.4mm to 4.0mm, No.122-140



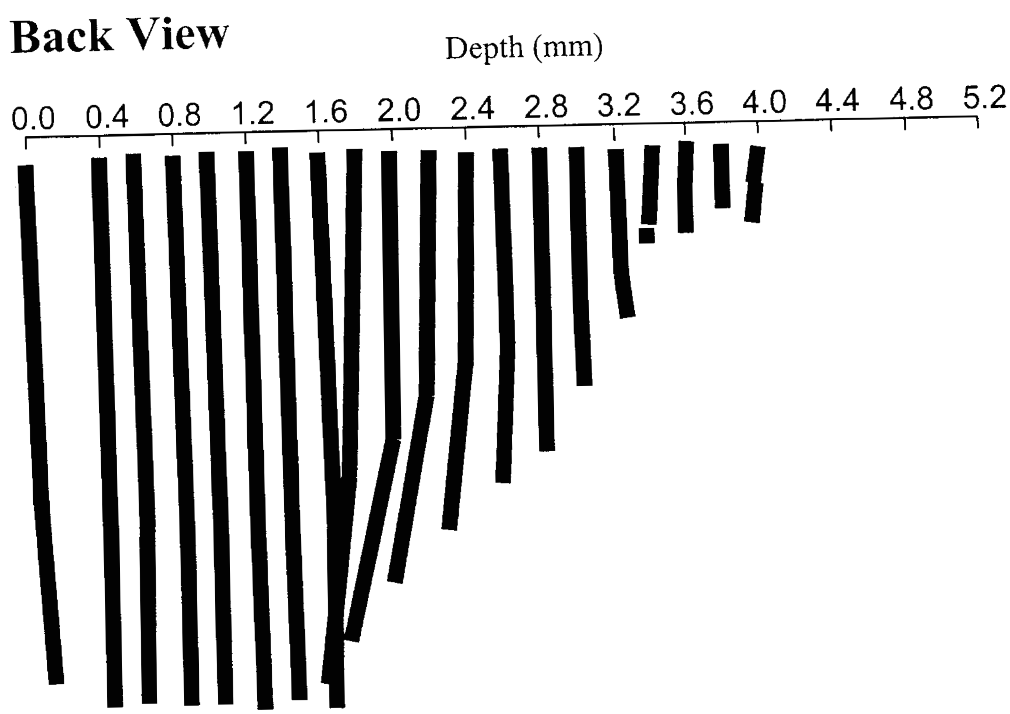
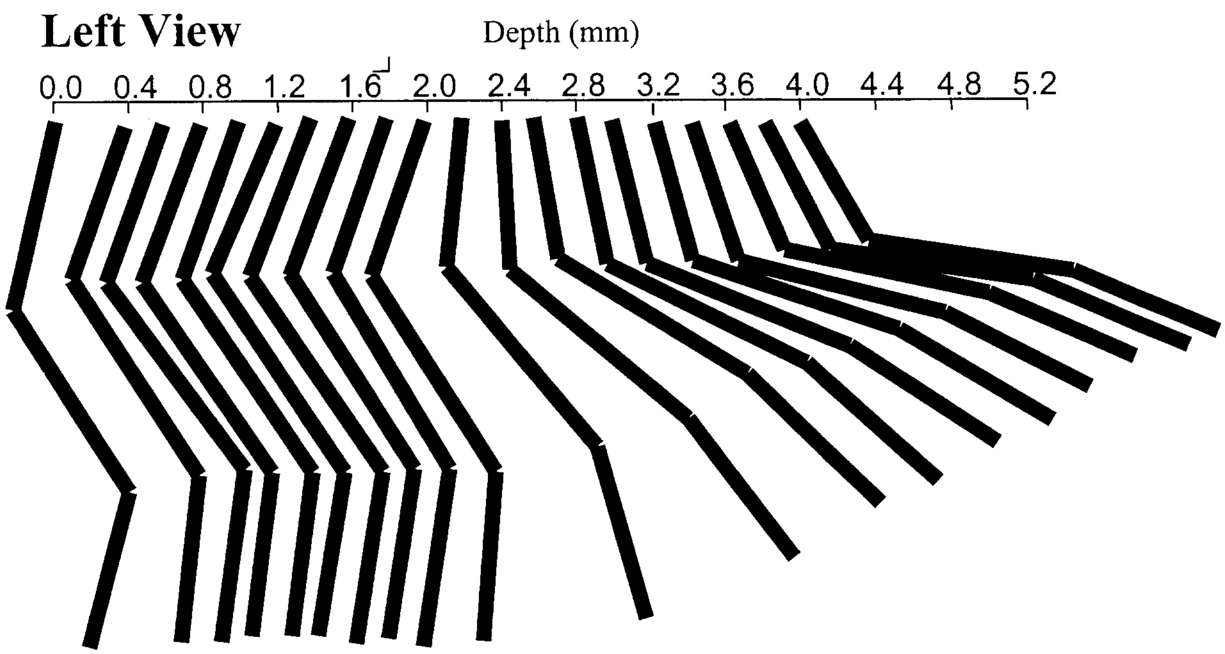


Figure 5

MS#82, Track#13, depth 0.4mm to 4.0mm, No.218-236



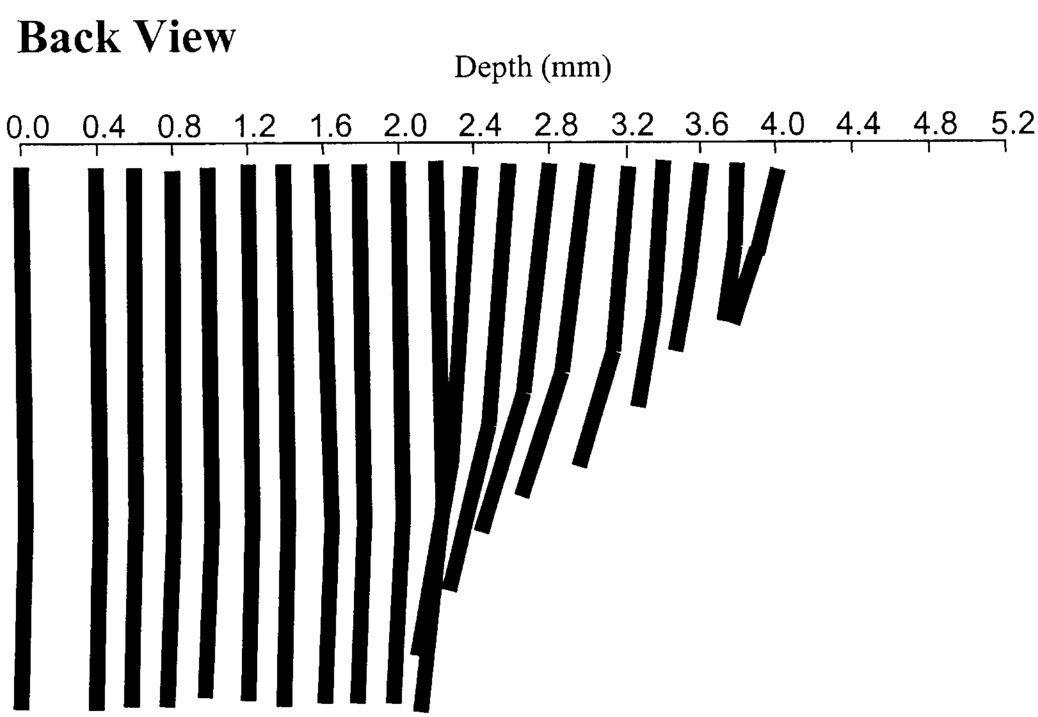


Figure 6